zipline

August 14, 2020

Submitted via electronic mail

Michael Halloran
Aviation Safety Inspector, Federal Aviation Administration
AFS-210, Technical Operations Branch
800 Independence Avenue, SW
Washington, DC 20591
E: *Michael.J.Halloran@faa.gov*

Subject: **Zipline -- Response to FAA's RFI dated August 7, 2020 (Docket No. FAA-2020-0499)**

Dear Mr. Halloran:

We are in receipt of your letter of August 7, 2020 (the "*RFI*") seeking further information in connection with Zipline's petition for exemption under 14 C.F.R. Parts 91 and 135 and 49 U.S.C. § 44807 (the "*Petition*") to operate our unmanned aircraft system ("*Zip UAS*") to make medical supply deliveries in the United States.[1] For ease of reference, each response set forth in Attachment A corresponds to the bold, italicized question that immediately precedes it, each of which has been reproduced from the RFI in the order presented.

This information is being submitted on a confidential basis pursuant to 14 C.F.R § 11.35(b), as it contains confidential commercial and proprietary information that would materially harm Zipline's competitive position if it were publicly disclosed. The information contained is not generally available to the public, is commercially sensitive, confidential, and proprietary, and is protected from release under the Freedom of Information Act, 5 U.S.C. §552 *et seq*.

Should you have any questions, or if any additional information would be helpful in evaluating the Petition, please do not hesitate to contact us.

Very truly yours,

Conor French — Okeoma Moronu

Conor French
General Counsel

Okeoma Moronu
Legal Counsel

[1] Capitalized terms used but not otherwise defined herein have the same meaning as in the Petition.

Copies to: Rachel Carlstrom, National IPP Program Manager, FAA
Russell Viall, Aviation Safety Inspector, Part 135 Air Carrier Ops Branch AFS-250, FAA
Basil Yap, UAS Program Manager, NCDOT
Thomas Davis, Aviation, NCDOT

ATTACHMENT A

Further Information Requested

THIS DOCUMENT, IN ITS ENTIRETY, INCLUDING ALL SUBSECTIONS AND FIGURES, CONTAINS ZIPLINE CONFIDENTIAL PROPRIETARY/TRADE SECRET INFORMATION.

Zipline's petition for exemption is requesting relief from CFR 91.119(b) and (c), Minimum Safe Altitudes. The FAA requests further information, specifically:

- ***The maximum population density of the potential operating areas and potential flight paths.***

The maximum population density of our potential operating areas and flight paths is approximately 6,000 persons per square mile. The average population density of these potential operating areas and flight paths is approximately 350 persons per square mile. Our System Analysis and Safety Assessment demonstrates safety in potential operating areas of up to 8,000 persons per square mile uniform population density.[2]

- ***Historical data of:***

  Unless otherwise stated herein, all historical data included in our responses below reflects production operations of the Zip UAS (using the Zip commonly referred to as "Sparrow") across Ghana, Rwanda, and the United States[3] as of August 12, 2020. With the following total flight experience:

  Flights: 8,600+
  Flight hours: 9,000+ hours
  Miles flown: 590,000+ miles

  - ***The number of fly-aways, lost links, accidents, and encounters with non-participating aircraft.***

    Number of fly-aways[4]: 0
    Lost links[5]: 1
    Accidents[6]: 0

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[2] *See* System Analysis and Safety Assessment, Section 6.1 *Probability of Collision Given Event.*

[3] Includes operations conducted in partnership with Novant Health to deliver medical supplies in the greater Charlotte metropolitan area. These operations are authorized under a Part 107 waiver granted to Novant Health.

[4] A "fly-away" is defined as any flight in which a Zip departs from its flight corridor and does not immediately respond as designed by deploying its Paraland System.

[5] A "lost link" is defined as any loss of all forms of communications with a Zip for a period of more than three minutes. Note that this dataset ***excludes*** international flights due to cell coverage availability in those operating environments that is materially different from cell coverage in our proposed operating environments in the United States.

[6] An "accident" is defined as a flight that concludes in a crash or mid-air collision, including any near midair collision.

Encounters with non-participating aircraft[7]: 1 -- a non-participating aircraft passed behind a Zip at a distance of 119 feet vertical and 1,894 feet horizontal

- ***The number of required unscheduled landings.***

  Number of unscheduled landings[8]: 3
  - 1 -- Inability of Zip to maintain altitude due to long climb, fore motor failure and challenging environmental conditions
  - 1 -- Strong tailwind pushed Zip outside of its flight corridor
  - 1 -- Birdstrike resulted in damage to Zip's motor pods

  None of these three unscheduled landings were commanded by the Controller and none of them resulted in damage to persons or property.

- ***The frequency or number of motor failure rates.***

  Number of motor failures[9]: 2
  - 1 -- Resulted in a paraland (*also included in the unscheduled landing data in our response above*)
  - 1 -- Lost motor function due to fore motor fault, recovered nominally on aft motor

- ***The frequency or number of departures from stable flight conditions.***

  Number of departures from stable flight conditions[10]: 2
  - 1 -- Insufficient thrust on one motor (*also included in both motor failure and unscheduled landing data in our responses above*)
  - 1 -- Strong tailwind beyond envelope resulted in Zip's departure from its flight corridor (*also included in the unscheduled landing data in our response above*)

- ***A description of any flights that differed in any way from the original plan.***

  In responding to this request, we defined a flight that "differed in any way from the original plan" as any flight in which our system did not perform as expected and, as a result, issued a fault while in flight. This summary of Zipline's historical data is inclusive of the incidents and events described in more detail in our responses above.

[7] "Encounters with non-participating aircraft" is defined as any known loss of well clear.

[8] An "unscheduled landing" is defined as any flight that concludes in a paraland prior to returning to the Nest.

[9] A "motor failure" means any time a motor experiences a fault that causes the motor to cease operating during a flight.

[10] A "departure from stable flight conditions" means any flight in which a Zip has flown outside the limit of its flight bounds.

Number of occurrences	Event description	Flight termination
170	Faults detected prior to delivery resulting in an inability to complete a delivery	All flights terminated with normal recovery except for: (i) two Controller-commanded alternative landings[11] and (ii) one paraland
125	Faults detected after successful delivery	All flights terminated with normal recovery except for: (i) four Controller-commanded alternative landings and (ii) two paralands

- ***The accuracy and precision of this GPS based altimetry system, according to the manufacturer, during all sUAS operating conditions.***

  Below are manufacturer-reported specifications for a Zip's primary and backup Global Navigation Satellite Systems ("*GNSS*"):

  Primary GNSS: Novatel OEM719 that is both L1/L2 and real-time kinematic ("*RTK*") enabled.

  The manufacturer datasheet reports the following location accuracy (expressed as root mean square) for these modes:
  - L1/L2: 1.2 meters (47 inches)
  - RTK: 1 centimeter + 1 part per million (0.4 inches + 1 part per million)

  Backup GNSS: Ublox F9P that is L1/L2 enabled. RTK is not currently enabled.

  The manufacturer datasheet reports the following location accuracy (expressed as root mean square) for these modes:
  - L1/L2: 1.5 meters (59 inches)
  - RTK: 1 centimeter + 1 part per million (0.4 inches + 1 part per million)

- ***Is GPS geometric altitude computation the primary source of altitude for the sUAS?***

  Yes. Either the primary or backup GNSS system described in our response above is the primary source of altitude for the Zip UAS; however, inertial measurement units ("*IMU*") and pressure altitude data are leveraged to augment this GNSS data to improve accuracy and robustness of position data.

  Zipline has developed a state estimation filter referred to as "*ZipNav*" that consumes IMU, GNSS, and pressure altitude measurements and estimates a Zip's position, velocity, and

[11] An "alternative landing" is defined as any flight that terminates in a paraland at the Nest.

orientation.[12] During flight, such positions are typically accurate to within a few centimeters and orientation is typically accurate within one degree.

Zipline's petition for exemption is requesting relief from CFR 91.121, Altimeter Settings. The FAA requests further information from the Zipline, with regard to the Sparrow UAS concerning:

- ***The number of historical failure rates of your GPS and barometric pressure based system.***

  We have experienced one failure of a Zip's primary GNSS system. This failure resulted in fault after delivery and successful recovery using the Zip's backup GNSS system.

  Additionally, we have experienced zero Air Data[13] failures.

- ***The frequency of calibration of your altimeter sensing systems.***

  Prior to each launch of a Zip, ZipNav leverages multiple sensors (as more particularly described in our response above) to estimate the Zip's position and this estimate is compared to the known launch position to confirm sensor health during pre-flight system checks.[14]

- ***Any failures of the system that caused accidents or incidents in the past.***

  None.

With regard to the Zipline Sparrow aircraft and the Unmanned Aircraft System, we need answers to the following questions:

1. ***What is the maximum distance (horizontal) that the aircraft will drift after deploying the Paraland system, considering deployment at:***
   a. ***The maximum altitude (400 AGL),***
   b. ***The maximum allowable speed for deployment (95 kts?), and***
   c. ***With the most unfavorable allowable wind component (tailwind)?***

   At a maximum altitude of 400 feet AGL, flying with a maximum allowable flying speed of 95 knots and a maximum tailwind of 19 knots, a Zip is expected to drift downrange approximately 1,063 feet after deploying its Paraland System.

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[12] *See* Unmanned Aircraft Flight Manual ("UFM"), Section 7.2.6 (*INS/Position Estimation*).

[13] The air data system is made up of two pitot tubes on each wing of the Zip used to determine pressure altitude and airspeed magnitude and direction. See UFM, Section 7.2.8.1 *Pitot Static System*.

[14] *See* UMM, Section 4.1.1 (e) *Preflight Inspection*

2. ***Can the controller command the aircraft to change its current flight route after the aircraft self-commands a:***
    a. ***return to nest, or***
    b. ***Paraland?***

    Yes. The Controller can command a Zip to ”Go To Hold” after the Zip self-commands a Return to Nest. In the event that a Zip determines an unsafe condition is present and self-commands a paraland, the Controller does not have an opportunity to override such a decision.

3. ***Does the aircraft make a barometric correction for its altitude control and reporting system prior to take-off and/or during flight? If so, describe in detail how the barometric correction system works?***

    Yes. A Zip makes a barometric correction for its altitude control and reporting system prior to each launch.

    As described in our responses above, ZipNav compares navigation sensors, including pressure sensors, before and during each flight to identify anomalies. Zips use the GPS coordinate frame for guidance and navigation. This absolute altitude is communicated from a Zip to the GCS. The GCS communicates both the GPS and pressure altitude of Zips to the Controller.

    The translation from GPS altitude to pressure altitude follows the ADS-B standard of using 29.92 inches of mercury for accurate comparison of pressure altitude between ADS-B reporting aircraft and Zips by the Controller.

4. ***What is the error tolerance for the barometric correction system?***

    Guidance and navigation use GPS altitude so they do not rely on barometric correction systems. Instead, ADS-B standard correction is used to translate the Zip altitude to pressure altitude for Controller airspace situational awareness.

5. ***What is the aircraft’s altitude error tolerance during flight operations, considering:***
    a. ***The aircraft’s flight control systems error tolerance (in feet) for maintaining a desired altitude?***
    b. ***The error (in feet) for the Zips system that the flight control system uses as a reference for maintaining desired altitude.***
    c. ***The total possible altitude error considering the two factors above, i.e. total possible error.***

        Typical maximum or minimum vertical tracking error on a flight is approximately 11 feet. A typical standard deviation of vertical tracking error is less than three feet.

        Vertical navigation error is typically about one inch with RTK GNSS. In the event a Zip loses RTK GNSS, this navigation uncertainty increases up to approximately eight feet.

        Considering these two factors, the expected total possible altitude error is 36 feet (28 feet + 8 feet) from the commanded path altitude.

6. ***What is altitude error (in feet), and position error (in feet) for the Path Planner database?***

   The Path Planner's obstacle and digital surface model accuracy is typically between three and 16 feet in both vertical and lateral dimensions.

7. ***How does Path Planner account for temporary or new obstacles (such as construction cranes, MET towers, etc.)? What are your procedures to mitigate these conflicts?***

   Path Planner plans routes to avoid all known obstacles. There is a possibility of temporary or new obstacles existing on a route without being represented in the Path Planner database.

   Zipline has put in place the following mitigations related to temporary or new obstacle risk:

   1. Using recent LIDAR or other survey data, as available and when practical
   2. Updating the obstacle database regularly as more information becomes available and checking flight path clearance from updated obstacles
   3. Community outreach and engagement in the operating area with a focus on delivery sites
   4. Flying higher above the ground (within maximum operating altitude limits) in areas with higher obstacle uncertainty or risk
   5. Conducting UAV aerial surveys of regions which may lack accurate information taking into account other data sources, as appropriate
   6. Manual comparison of obstacle database with aerial or satellite imagery to spot obstacle discrepancies
   7. Leveraging alternative data sources, as applicable and practical, such as the FAA's obstruction evaluation database, powerline databases, and cell tower databases
   8. In-person delivery site visits and route reconnaissance, as appropriate and when practical

8. ***How long does it take the recovery system to reset to accept another Zip to be recovered after the first Zip is initially captured by the Recovery system?***

   The recovery system takes approximately 20 seconds to reset between recoveries.

9. ***How many recoveries have been missed or aborted? What does the aircraft do when it misses or aborts a recovery attempt? How long does it take for the Zip to return for another attempt?***

   Number of successful recoveries in dataset: 8,647
   Number of recoveries requiring multiple attempts: 415 (or less than 5% of all recoveries)

   If a Zip misses the recovery system's automated arresting line, the Zip will automatically ascend to re-enter the recovery path for another recovery attempt.[15] The Zip will continue to attempt to recover nominally until it hits a minimum battery threshold and the Controller is alerted to initiate an alternative landing. The Controller will receive both audio and visual cues when the Zip has only five minutes of battery time remaining, including a countdown display for situational awareness.

The time between recovery attempts is typically less than two minutes. Of the missed recoveries, 353 (or approximately 4% of all recoveries) were successfully recovered on the second attempt and all such missed recoveries were successfully recovered within six attempts.

10. What is your proposed minimum battery reserve (in minutes)?

Flight routes are only approved if there is a minimum of ten minutes of battery reserve.[16]

11. What is the maximum number of failed recovery and delivery passes as indicated in your petition for exemption? How much flight time is planned to perform each of these maneuvers?

Maximum number of failed delivery passes: A Zip may make up to three delivery attempts, depending on the relevant flight plan. On longer routes, a Zip may be permitted to make only one delivery attempt.

Maximum number of failed recovery passes: A Zip will continue to attempt to recover nominally until it hits a minimum battery threshold and the Controller is alerted to initiate an alternative landing as described in our response to Question 9 above.

Typical times for recovery and delivery re-attempts are each less than two minutes. However, the energy analysis for each flight route is completed in simulation along the actual flight path. The actual time and energy expenditure (accounting for time, climb, and descent rates, etc.) required to complete the delivery and recovery attempts is taken into account in the route energy validation.

12. How does the PIC determine the Minimum Battery Reserve prior to each flight? Is this displayed or readily available at the Pilots ground control station? How does the pilot retrieve this information?

The Charger Mini App, which is part of the Zipline App, allows the Controller to monitor the charging status of all Zip batteries.[17] Only fully charged batteries are utilized during flights. The battery endurance limitation has been set at two hours.[18] Notwithstanding this limitation, our test facility has demonstrated the batteries have over three hours of endurance.

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[15] *See* UFM, Section 4.6 *Missed Capture*.

[16] *See* General Operations Manual, Section 4.7.2 (*Flight Route Planning, Validation and Approval (Strategic Collision Avoidance)*).

[17] *See* Unmanned Aircraft Flight Manual, Section 7.4.6 (*Chargers*).

[18] *See* Unmanned Aircraft Flight Manual, Section 5.1.4 (*Endurance*).

The Controller can retrieve battery data from the GCS.

- The Charger Mini App displays, among other things, (i) whether a battery is fully charged, (ii) real time volts, amps, and temperature, and (iii) any abnormal events.[19]
- The Controller Mini App, which is also part of the Zipline App, displays the battery charge percentage at all times once the battery is attached to the Zip. The Controller will receive both audio and visual cues when the Zip has only five minutes of battery time remaining, including a countdown for situational awareness[20].

13. Are the following items displayed/ provided at the pilots ground control station:

a. Battery Charge Remaining? What is the unit of measure for this?

b. All pilot to aircraft links that are currently in use for communication with the aircraft, (LOS, Cell, and SAT)?

c. Is the pilot alerted to a loss of link? Are these alerts available for all 3 types of pilot to aircraft communications that are currently available? How is the pilot alerted for a loss of link?

a. Yes. The battery charge remaining is displayed and available to the Controller at the GCS. Battery charge is displayed in terms of percentage remaining.

b. Yes. All pilot to aircraft links that are currently in use for communication are displayed and available to the Controller at the GCS. The status of line-of-sight ("*LOS*") and cellular connectivity displays as blue and red hash marks, respectively, on the Controller Mini App. Backup satellite communications are displayed on BirdWatch.

c. Yes. The Controller is alerted to loss of primary communications links. During a loss of both LOS and cellular connectivity, the area on the Controller Mini App that displays the LOS and cellular connectivity information on each flight's information window will shift from showing blue tick marks (LOS) and/or red hash marks (cellular) to displaying a solid yellow line. The Controller Mini App will also audibly call out "Loss Comms". There is currently no alert for loss of backup satellite communications capabilities.

[19] See UFM, Section 7.4.6 (*Chargers*).

[20] *See* UFM, Section 4.6 *Missed Capture.*